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PHASE II

"DETERMINATION OF THE WELDING CONTROL

PARAMETERS AND REQUIREMENTS

FOR

THE AUTOMATION OF OUT-OF-POSITION WELDING"

CONTRACT NO. NAS8-2601

INTERNATIONAL AIRPORT LOS ANGELES 9, CALIFORNIA

LOS ANGELES DIVISION

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Report No. NA-62-864-1

NORTH AMERICAN AVIATION, INC.

INTERNATIONAL AIRPORT
LOS ANGELES 45, CALIFORNIA

Phase II

"DETERMINATION OF TIG WELDING CONTROL PARAMETERS AND REQUIREMENTS

FOR

THE AUTOMATION OF OUT-OF-POSITION WELDING"

CONTRACT NO. NAS8-2601

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rf

REVISIONS

Date 27 November 1962

DATE	REV. BY	PAGES AFFECTED	REMARKS

FOREWORD

This report presents the work accomplished for the Phase II part of NASA Contract NAS8-2601, "Determination of TIG Welding Control Parameters and Requirements for the Automation of Out-of-Position Welding." This report includes the results obtained with out-of-position automatic welding two aluminum plate alloys with three oscillator mechanisms.

TITLE: Phase II - Determination of TIG Welding Control Parameters and Requirements for the Automation of Out-of-Position Welding.

AUTHOR: J. M. Lambase

27874

ABSTRACT: In Phase II an oscillator was designed and built that has an adjustment mechanism for varying bead width during the welding operation. This oscillator produced satisfactory weld joints. A comparison investigation conducted between the cross seam, radius, and adjustable oscillators indicated no appreciable differences in weld quality, bead appearance and heat affected zones for joints made with the three oscillators. Automatic welding was performed in the vertical (travel up and down) and the overhead positions. Excellent side wall and interpass fusion was obtained in 2014 and 5456 aluminum plate alloys welded in these positions. Work accomplished in Phase I has been reported in Reference (a).

Author

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Extensive out-of-position welding will be required for on site space vehicle fabrication. These vehicles may require welds up to 150 feet long. When out-of-position vertical welds are made manually excellent fusion can be obtained at the joint side walls. A convex bead is formed that blends into both side walls eliminating notches. A disadvantage of the manual operation is that it is time consuming since the welder cannot make long weld passes without frequent starting and stopping. Another factor to consider when making manual welds on large structures is the possibility of weld quality variation due to operator fatigue and judgement. It would be desirable to develop a mechanism which simulates the manual weave bead technique and which could be attached to commercially available automatic TIG equipment. This mechanism should have an adjustment for varying bead width from 0 to $1\frac{1}{2}$" and for changing the direction of the arc as it approaches the joint side walls. The welding equipment should have a high degree of functional and repetitive reliability, minimize operator decision and surveillance, and be a relatively low cost flexible unit.

1. OBJECTIVES

1.1 Design an oscillator that will have an adjustment for changing the bead width during the welding operation.

1.2 Weld panels in the vertical position with the cross seam , radius, and variable weld bead adjustable oscillator and compare results obtained with each oscillator.

1.3 Weld panel in the overhead position with the adjustable oscillator.

2. MATERIAL

The following aluminum materials were used in the Phase II investigation:

Material	THK	Nominal Percent Chemical Composition							
		MN	MG	CR	SI	FE	CU	ZN	TI
5456	3/8", 1/2", 3/4"	.15	1.0	.25	.6	.7	.3	.25	.15
2014	1/2"	.8	.4		.8		4.4		
43S Filler Dia.	1/16"	.05	.05		5.25	.8	.3	.1	.2

3. EQUIPMENT

3.1 The radius, cross seam, and weld bead width adjustable oscillators shown in Figures 1, 2, 3, 4, 5, 6 were designed, built and tested. The radius oscillator provides a motion that changes the direction of the arc as it approaches the joint side walls. The arc is directed at the side wall at an angle of 45 degrees. There is no angular change in the position of the arc with the cross seam oscillator motion. The weld bead adjuster oscillator arc motion is similar to the radius oscillator, however, the bead width can be varied during the welding operation with the adjustable oscillator. All three oscillators are air driven with frequencies ranging from 0 to 300 rpm. Oscillator amplitudes can be varied from 0 to 1 1/2 inch. The Airco water cooled torch (Model-50A) shown in Figure 1 was positioned in the oscillator. Two percent thoriated tungsten electrodes were used throughout the program.

3.2 A Vickers selenium rectifier power supply (300 amp) and direct current - straight polarity current was used to weld the test panels. Arc voltage control was not used with the test apparatus mounted on the milling machine bed. (See Figure 7). A Honeywell Viscorder was used to record amperage and voltage outputs and torch oscillation frequencies.

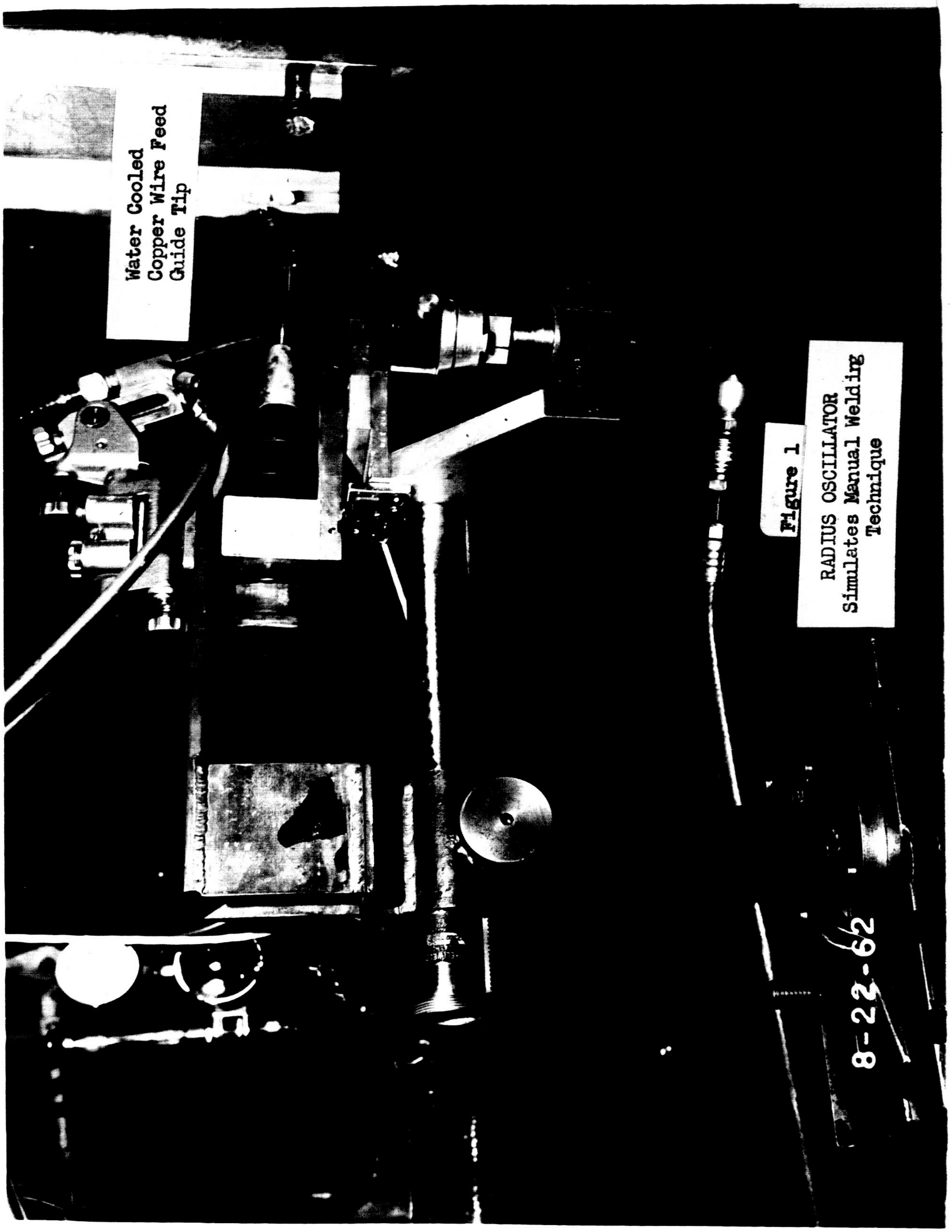


Figure 1
RADIUS OSCILLATOR
Simulates Manual Welding
Technique

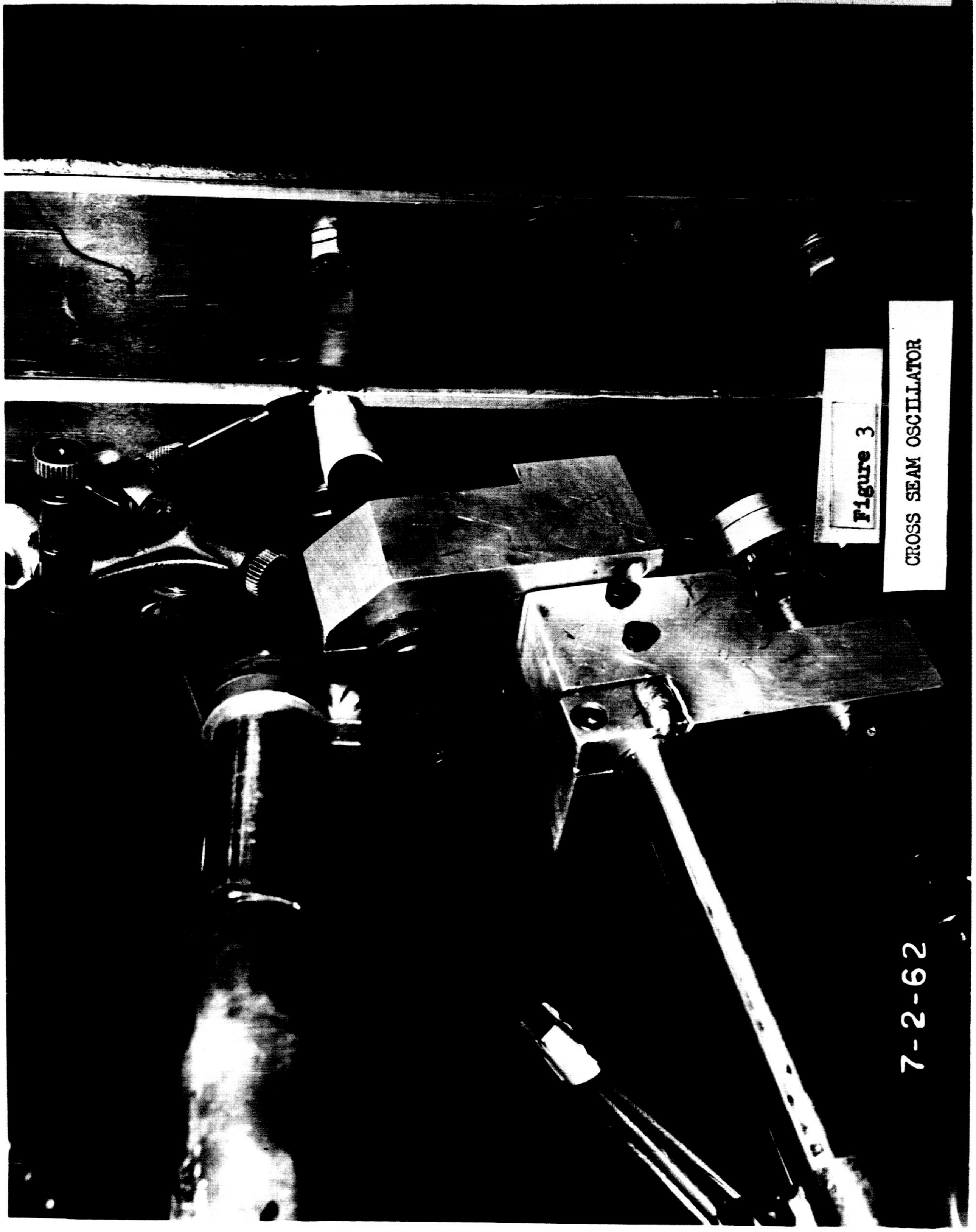


Figure 3

CROSS SEAM OSCILLATOR

Figure 5

PHOTOGRAPH OF
ADJUSTABLE OSCILLATOR

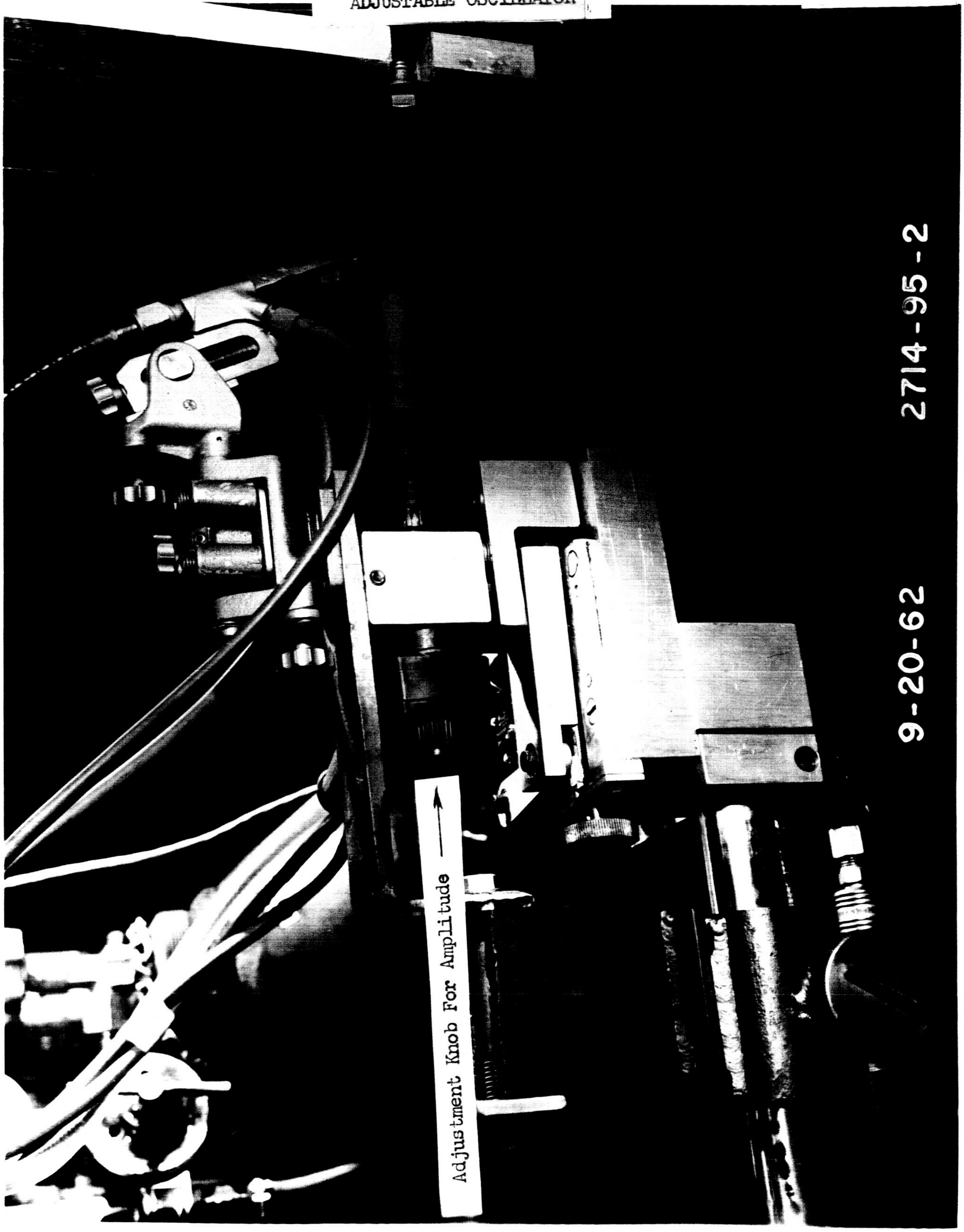
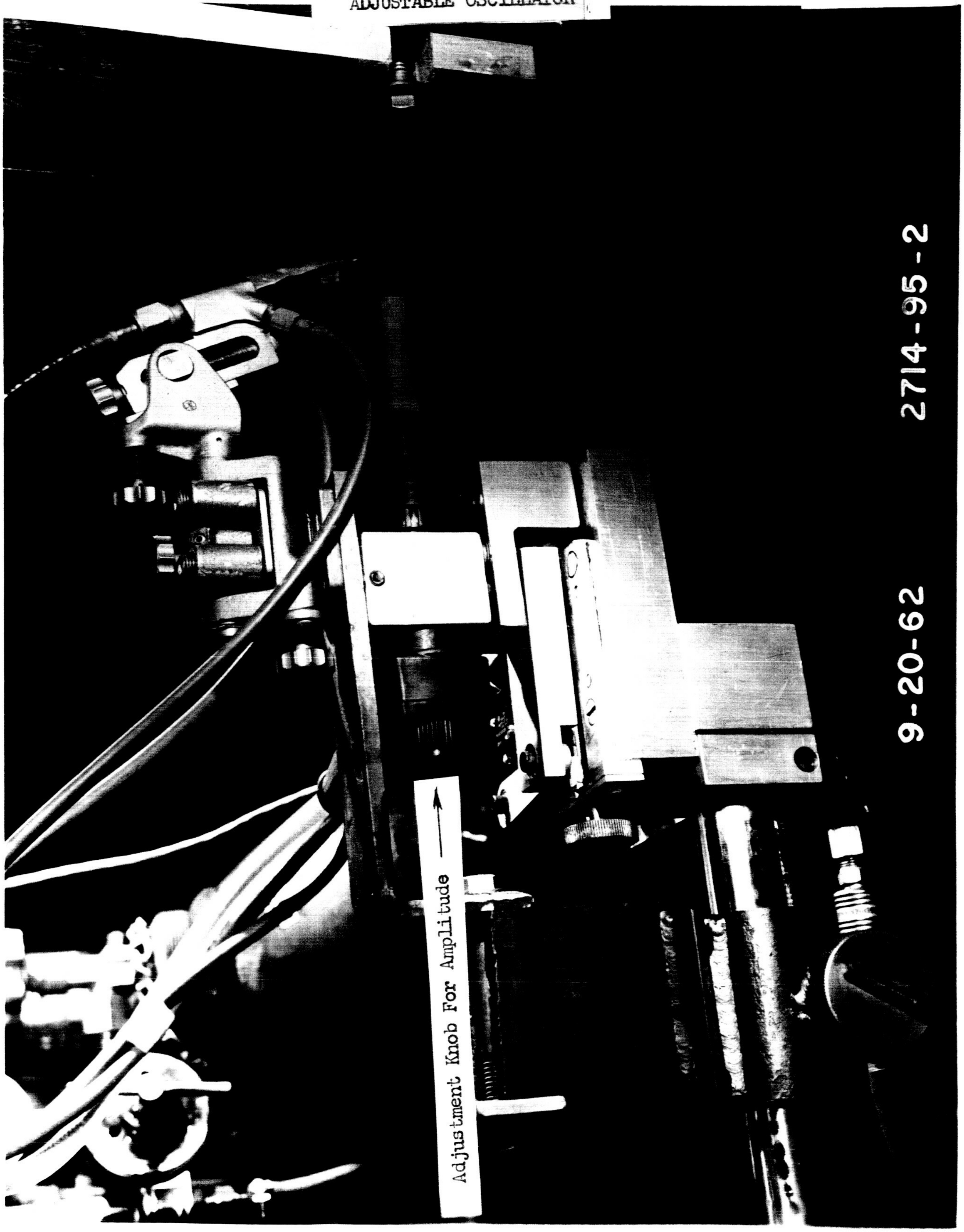


Figure 5

PHOTOGRAPH OF
ADJUSTABLE OSCILLATOR



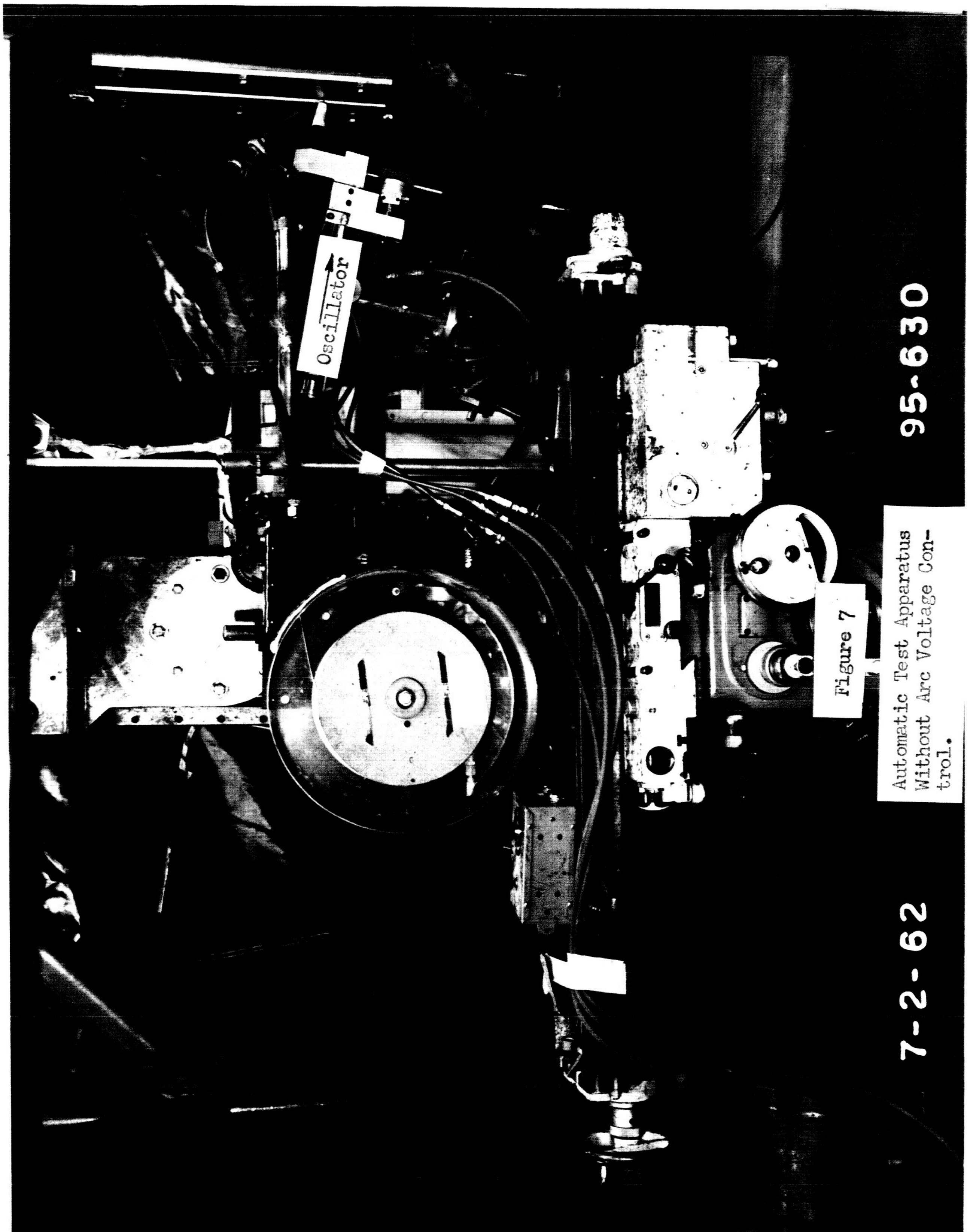


Figure 7

Automatic Test Apparatus Without Arc Voltage Control.

3.3 Wire feed drive was supplied by the Airco variable speed motor and guide rolls. Water cooled copper guide tips were used to feed the filler wire into the weld puddle.

4. PROCEDURE

4.1 The radius, cross seam and adjustable oscillators were attached to the test apparatus. Automatic welding was accomplished in the vertical up, vertical down and overhead positions (See Figures 7, 8, and 9). Welding parameters for these positions are reported in (Tables I thru VIII).

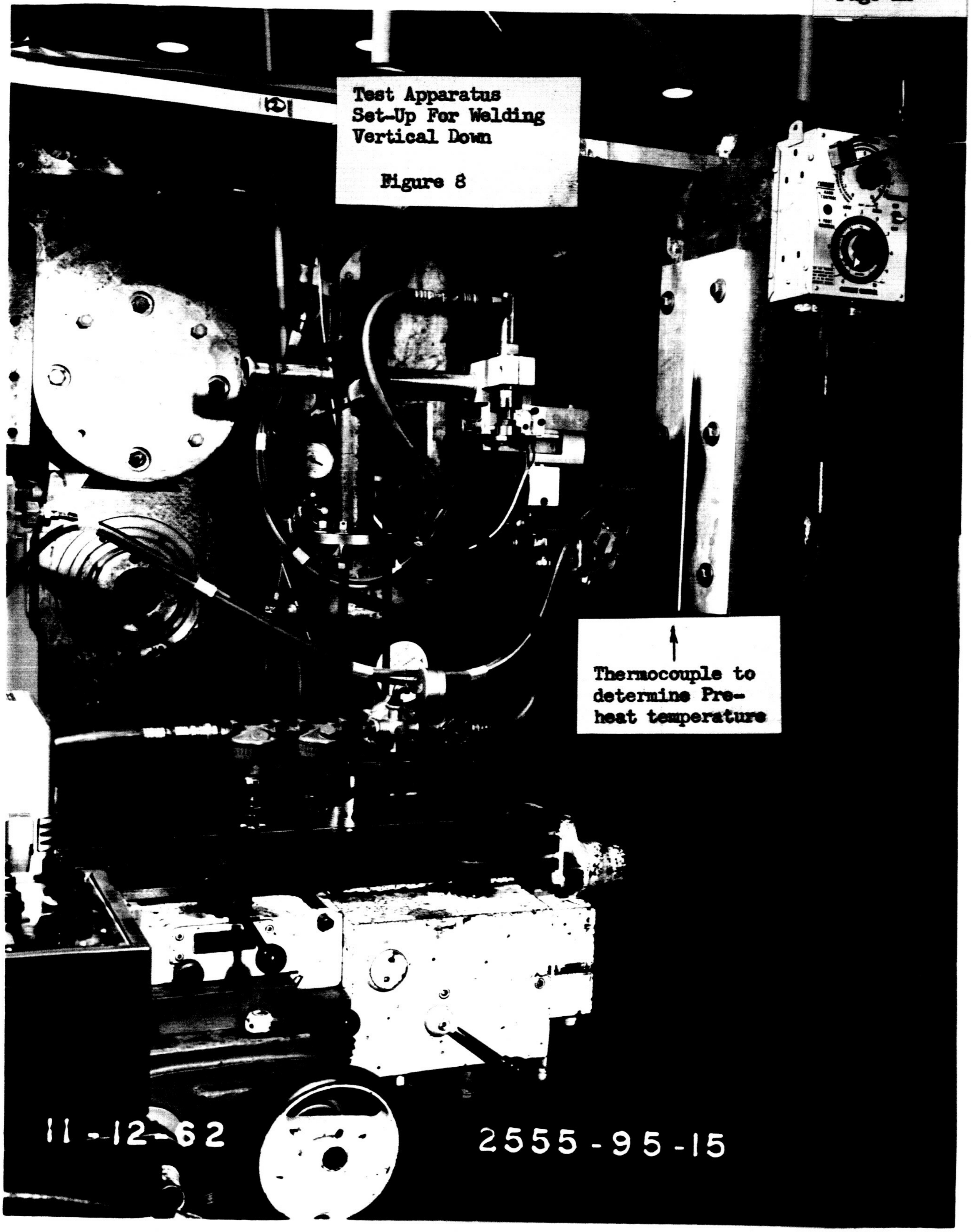
4.2 The joint design was the same for all the two-foot long test panels welded in the Phase II investigation (See Table I thru Table VIII). A root opening was not used at the butting edges. The machined joints were cleaned with acetone to remove shop lubricants, sanded with "Bear Tex" to remove the oxide, and then cleaned with acetone. Thereafter the test panels were handled with white gloves when being attached to the test apparatus. The 1/16" diameter filler wire was used in the as received condition.

4.3 During the welding operation the arc length was manually controlled. The operator maintained arc length by observing a voltmeter and making arc length adjustments when a change in arc voltage occurred.

4.4 The wire which was not oscillated with the torch, was added to the weld puddle preceding the torch in the direction of travel. The wire extended one half inch from the end of the copper wire feed guide tip prior to entering the puddle.

4.5 Preheating of the aluminum plates was accomplished using the tungsten torch. This was accomplished by moving the torch up and down a three inch distance at the start of the weld joint. A thermocouple was attached near the start of the weld (See Figure 8) to determine if the desiged root pass and interpass temperatures were being maintained during the welding operation. Preheating of the joint was not required after the initial root pass.

4.6 The welded joints were x-rayed and photomicrographs were prepared to evaluate side wall and interpass fusion.



Test Apparatus Set-Up For Welding Vertical Down

Figure 8

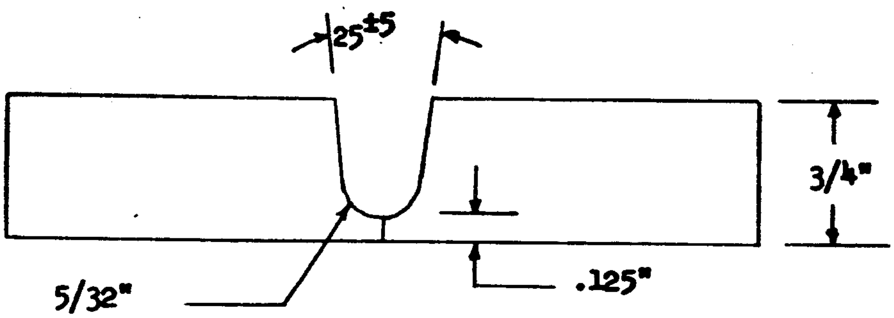
Figure 9

TEST APPARATUS SET-UP
FOR OVER-HEAD WELDING

Table I

CROSS SEAM OSCILLATOR
VERTICAL POSITION
AUTOMATIC TIG WIELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

Panel Code No. 5-22
5456 Al. Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFH
Travel Speed - 2.5 IPM
Tungsten Dia. - 1/8"



Joint Design

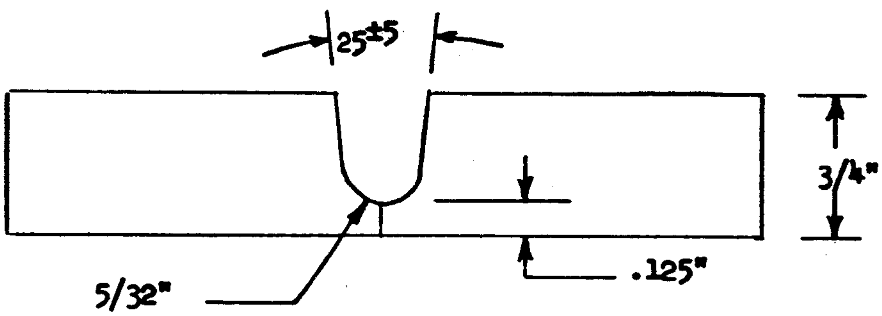
Variables	Weld Passes					
	1	2	3	4	5	6
Amperage	175	175	175	180	185	180
Voltage	12	13.5	14	14	14	14
Wire Feed - IPM	17	28	31	35	36	30
Oscillator Amplitude	None	1/8"	5/32"	3/16"	7/32"	7/32"
Oscillator Frequencies	None	90	100	90	90	90

Preheat - first 3 inches of joint heated to 130°F with TIG torch.
Interpass temp. - 125°F.

Table II
Data Sheet No. 2

RADIUS OSCILLATOR
VERTICAL POSITION
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

Panel Code No. 5-26
5456 Al. Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFM
Travel Speed - 2.5 IPM
tungsten Dia. - 1/8"



Joint Design

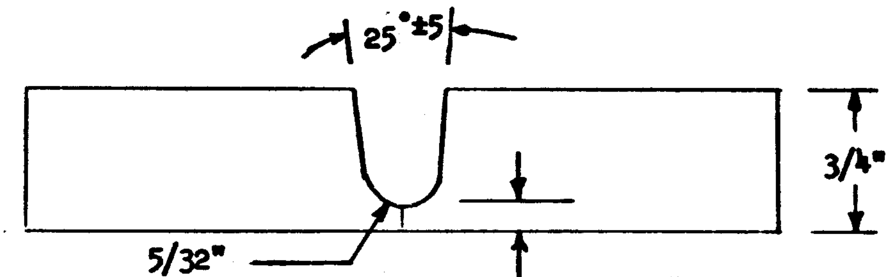
Variables	Weld Passes 1	2	3	4	5	6
Amperage	170	170	170	170	170	170
Voltage	13	14	14	15	15	14
Wire Feed - IPM	17	28	31	35	35	31
Oscillator Amplitude	None	1/8"	5/32"	3/16"	7/32"	7/32"
Oscillator Frequencies (CPM)	None	105	135	120	105	105

Preheat - First 3 inches of joint heated to 130°F with TIG torch.
Interpass temp. - 125F to 150F.

Table III
Data Sheet No. 3

ADJUSTABLE OSCILLATOR
VERTICAL POSITION
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

Panel Code No. 6-28
5456 Al. Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He CFH
Travel Speed - 2.5 IPM
Tungsten Dia. - 1/8"



Joint Design

Variables	Weld Passes 1	2	3	4	5	6
Amperage	175	175	180	180	180	180
Voltage	14	14	14	14	14	15
Wire Feed - IPM	21	24	28	32	32	40
Oscillator Amplitude	None	1/8"	3/16"	7/32"	9/32"	9/32"
Oscillator Frequencies	None	(1)	(1)	(1)	(1)	(1)

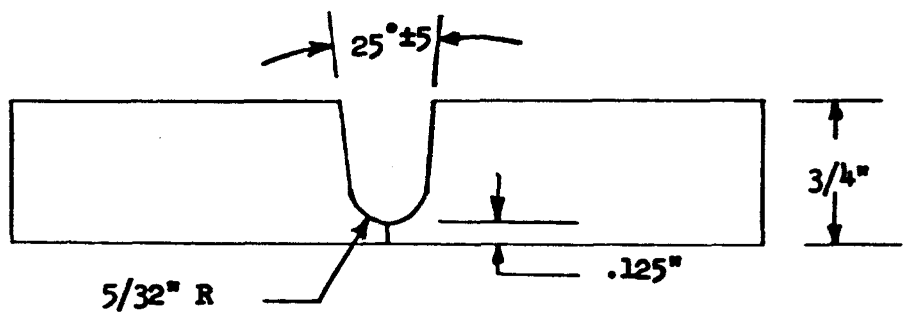
(1) Oscillation frequencies not recorded, however, it is believed to be between 100-125 CPM.

Preheat: First 3 inches of joint heated to 130°F with TIG torch.
Interpass temp. - 130°F to 140°F

Table IV
Data Sheet No. 4

CROSS SEAM OSCILLATOR
VERTICAL POSITION
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

Panel Code No. 6-30
5456 Al. Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFH
Travel Speed - 9 1/2 IPM
Tungsten Dia. - 1/8"



Joint Design

Variables	Weld Passes 1	2	3	4	5	6	7
Amperage	190	240	240	240	240	240	240
Voltage	15	15	16	15	15	15	15
Wire Feed - IPM	60	100	100	100	100	100	100
Oscillator Amplitude	None	1/8"	5/32"	3/16"	7/32"	1/4"	1/4"
Oscillator Frequencies	None	(1)	(1)	(1)	(1)	(1)	(1)

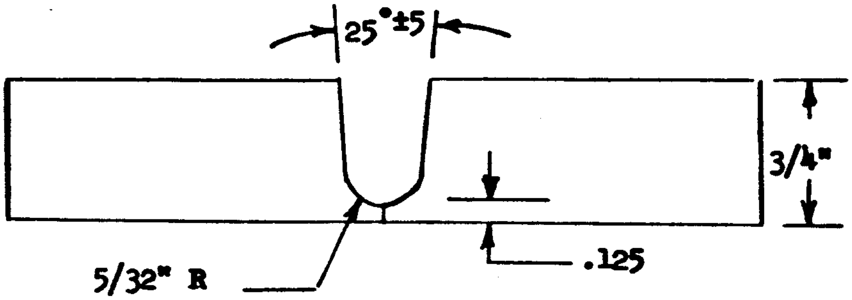
(1) Oscillation frequencies not recorded.

Preheat: First 3 inches of joint heated to 130°F with TIG torch.
Interpass temp. - 120 F - 130 F.

Table V
Data Sheet No. 5

ADJUSTABLE OSCILLATOR
OVERHEAD POSITION
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

Panel Code No. 8-5
5456 Aluminum Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFH
Travel Speed - 5 IPM
Tungsten Dia. - 1/8"



Joint Design

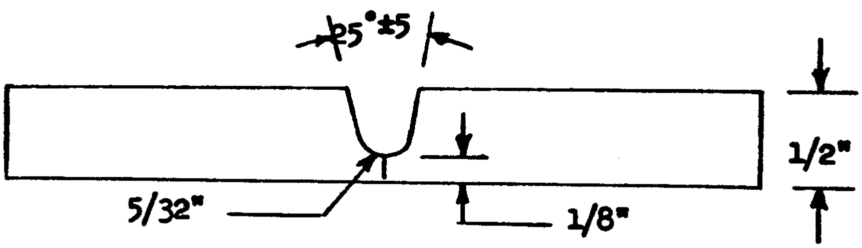
Variables	Weld Passes 1	2	3	4	5
Amperage	200	200	200	200	200
Voltage	14	16	16	16	16
Wire Feed - IPM	26	50	50	60	60
Oscillator Amplitude	None	1/8"	3/16"	1/4"	1/4"
Oscillator Frequencies (CPM)	None	240	240	240	240

Preheat: First 3 inches of joint heated to 130°F with TIG torch.
Interpass temp. - 130°F - 160°F.

Table VI
Data Sheet No. 6

ADJUSTABLE OSCILLATOR
VERTICAL POSITION
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

2014 Al. Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFH
Travel Speed - 2.5 IPM
Tungsten Dia. - 1/8"



Joint Design

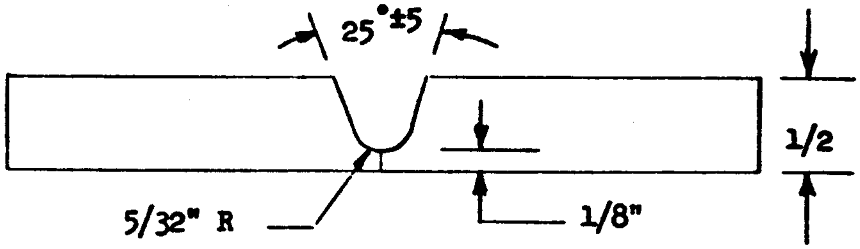
Variables	Weld Passes 1	2	3	4
Amperage	175	180	180	180
Voltage	15	15	15	15
Wire Feed - IPM	24	32	32	35
Oscillator Amplitude	None	1/8"	3/16"	3/16"

Preheat - First 3 inches of joint heated to 130°F.
Interpass temp. - 135°F.

Table VII
Data Sheet No. 7

ADJUSTABLE OSCILLATOR
VERTICAL POSITION
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

2014 Al. Matl.
Filler - 1/16" Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFH
Travel Speed - 2.5 IPM
Tungsten Dia. - 1/8"



Joint Design

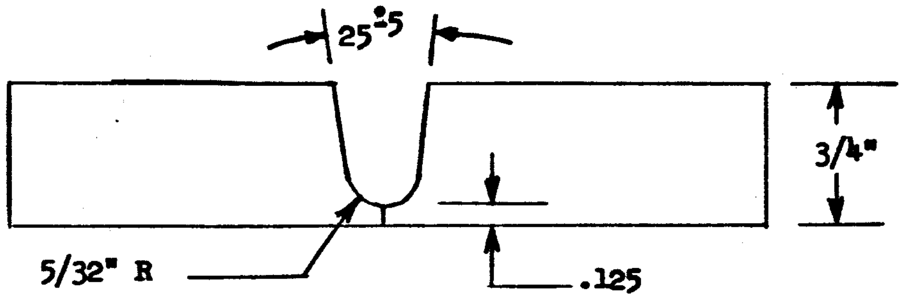
Variables	Weld Passes 1	2	3
Amperage	175	180	185
Voltage	15	15	15
Wire Feed - IPM	24	40	45
Oscillator Amplitude	None	1/8"	3/32"

Preheat - First 3 inches of joint heated to 130°F.
Interpass temp. - 140°F.

Table VIII
Data Sheet No. 8

ADJUSTABLE OSCILLATOR
VERTICAL POSITION-DOWN
AUTOMATIC TIG WELDING VARIABLES
WITHOUT ARC VOLTAGE CONTROL

Panel Code No. 10-2
5456 Aluminum Matl.
Filler - 1/16" - Dia. 43S
Current - DC-SP
Torch Gas Flow - He 90 CFH
Travel Speed - 5 IPM
Tungsten Dia. - 1/8"



Joint Design

Variables	Weld Passes 1	2	3	4	5	6
Amperage	170	180	180	195	195	190
Voltage	13	14	14	14	14	14
Wire Feed - IPM	26	44	57	65	65	65
Oscillator Amplitude	None	1/8"	3/16"	1/4"	9/32"	9/32"
Oscillator Frequencies (CPM)	None	240	240	240	240	240

Preheat - First 3 inches of joint heated to 130°F. Interpass Temp. - 140°F.

5. RESULTS AND DISCUSSION

5.1 The adjustable oscillator (See Figures 5 and 6) functioned properly. Figure 10 is a photograph of a bead-on-plate weld made with the adjustable oscillator. The amplitude of oscillation was continuously varied from 3/8" to 1 1/2" during the welding operation. The bead-on-plate edges blended into the base material without any undercutting. Satisfactory nulti-pass welds were made in the grooved joint with this oscillator (See Figure 11). These passes have a smooth appearance with even repetitive ripple pattern and the edges blended into the side wall without any undercutting. Similar type welds were produced with the other two oscillators (radius and cross seam). A typical weld joint produced with the oscillators is shown in Figure 12. Excellent side wall and interpass fusion was obtained with all three oscillators, however, the adjustable oscillator is preferred over the other oscillators. Both rotating oscillators will yield a greater guarantee of side wall fusion than the cross seam oscillator since the arc is rotated towards the side walls, but the adjustable oscillator presents the added ability of changing bead width as welding proceeds.

5.2 Satisfactory out-of-position welds were made at three travel speeds, 2.5 IPM, 5.0 IPM and 9.0 IPM. Above 9.0 IPM satisfactory welds could not be made because the operator was unable to make the proper adjustments with the test apparatus controls during the welding operation. Arc voltage and wire feed adjustments are the two welding variables which could not be changed or controlled satisfactorily above 9 IPM travel speed. Finer and more sensitive equipment controls are required to weld at faster travel speeds. Equipment control modifications will be designed and built in Phase III.

5.3 Several test welds were made using 3/32" diameter filler wire, however, it was difficult for the operator to make a satisfactory multi-pass weld with this wire diameter. The position of the 3/32" diameter wire with respect to the weld puddle is critical in the relatively narrow grove that is being welded. Any slight deviation of the wire feed from the center of the puddle interferes with the oscillating tungsten and adjustments to correct this deviation is difficult for the operator to make. With the smaller diameter wire, 1/16", the location of the wire with respect to the weld puddle is not critical. The wire can be feed into any part of the weld puddle and, if necessary, adjustments can be easily be made by the operator. The 1/16" diameter wire can be feed into the "U" joint with rates ranging from 15 IPM to 100 IPM. The 100 IPM is the maximum speed that can be obtained with the available wire feed motor, however it is believed that the wire could feed at faster rates with a higher speed motor.

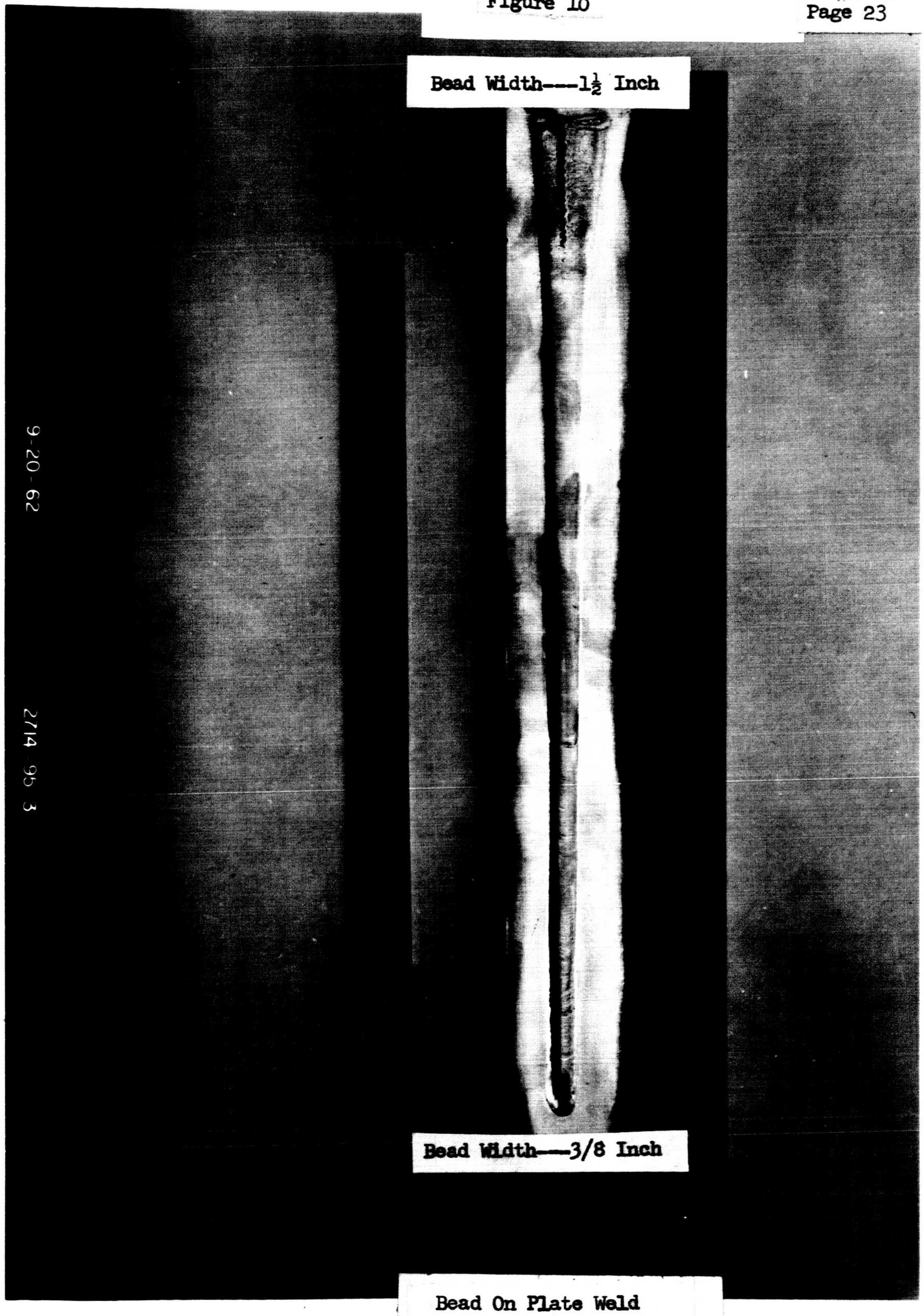
5.4 The adjustable oscillator was used to weld panels in the vertical up, vertical down and overhead positions. Similar and acceptable weld bead appearance was obtained in the three positions. These welds were made adding filler wire in front of the tungsten electrode with respect to weld travel direction. Wire feed addition and control were satisfactory with the wire ahead of the tungsten. A test weld was also made with the wire following the tungsten. Satisfactory welds could not be made in this way because the wire was being fed into the portion of the puddle where solidification is occurring. This solidification causes the wire to stick or break off. When the wire feed precedes the tungsten it is being fed into the portion of the puddle where melting occurs. This provides sufficient heat to continuously melt the wire and thereby eliminate the sticking problem.

5.5 Weld quality was evaluated on the basis of North Amercian Aviation Fusion Welding Specification (Reference (b)). All weldments were free of cracks, lack of fusion, and lack of penetration defects. Figure 12 is a photomacrograph of a typical weld. The multi-pass weld beads have a smooth appearance with an even repetitive ripple pattern, the edges of the welds blended into the base metal without overlap or undercut.

5.6 Considerable porosity was present in weld test panel 10-2. The photomacrograph shown in Figure 13 revealed that most of this porosity was concentrated in the initial weld pass. Root pass porosity was also considerable in panels 5-22 and 5-26. The drop thru was machined off these panels and the weld joint was re-X-rayed. The X-ray film revealed that a major portion of the porosity was removed from the weld joint. There was some porosity in the other weld passes, however, the size and distribution of the porosity was within the limits specified in the NAA welding specification. The use of back-up gas coverage during root pass welding would minimize or eliminate root pass porosity. Figure 14 and 15 shows a comparison of the root side of weldments made with an without gas back-up. The root pass surface is smooth, free of oxides and blends into the parent material when gas back up is used. This indicates that the root side is protected from air contamination which will produce considerable porosity. Gas back-up was achieved using a plastic chamber on the root side of the joint. Weld panels 6-28 and the 2014 test welds which had acceptable root passes (See Tables VI and VII) were made without backing gas, however, it is difficult to consistently reproduce satisfactory root passes without back-up gas.

5.7 Weld panel 6-28 contain tungsten inclusions which are not acceptable. During the joining operation the welder adjusts the torch to maintain the desired arc voltage. Sometimes due to over adjustment the tungsten touches the molten puddle and tungsten particles are added to the joint. This could be minimized by incorporating a more sensitive arc length control knob. This will be incorporated in the Phase III equipment.

Figure 10



Bead On Plate Weld
Made With
Adjustable Oscillator r

Figure 11

5456 3/4"THK ALUMINUM
PLATE WELDED WITH
ADJUSTABLE OSCILLATOR

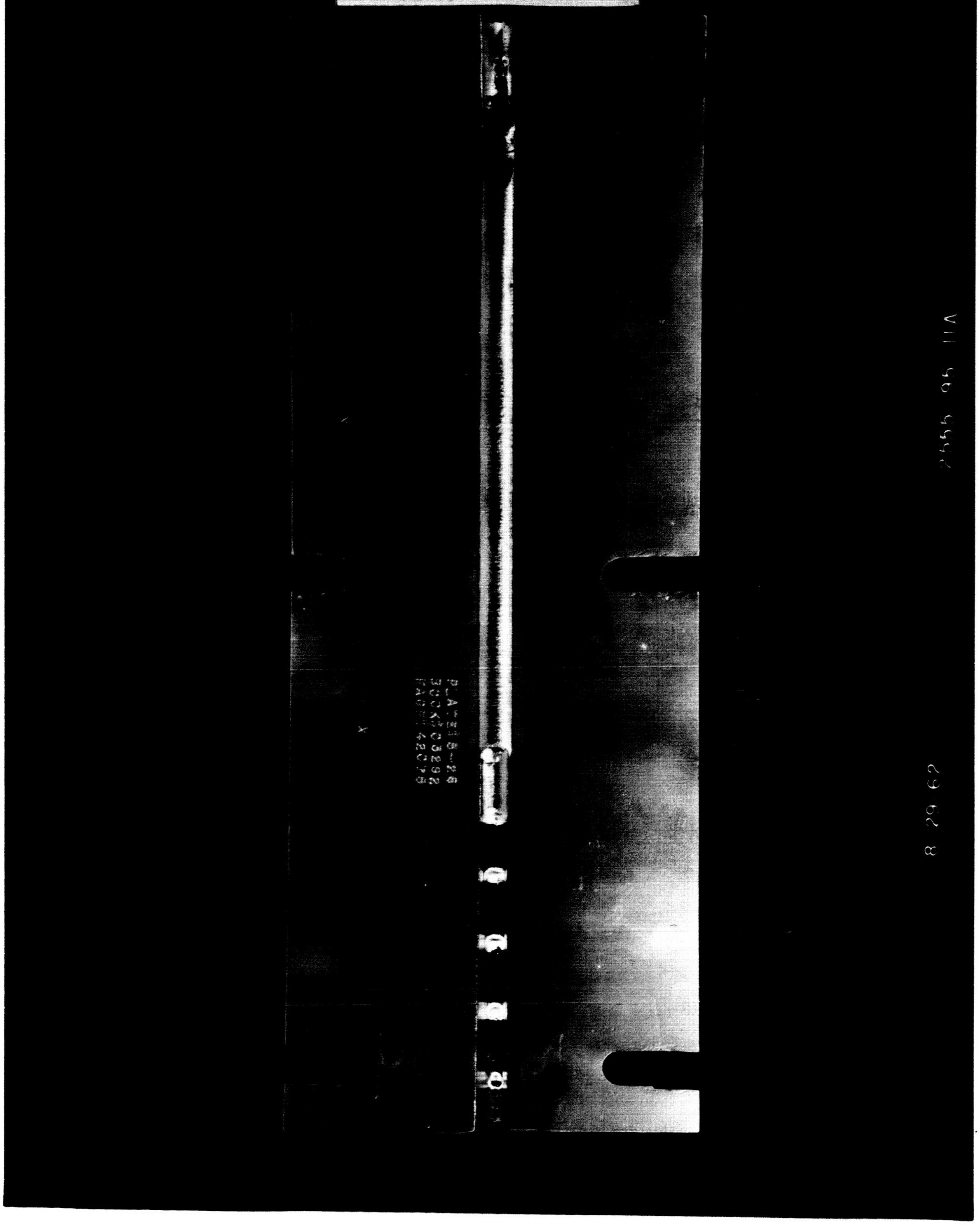
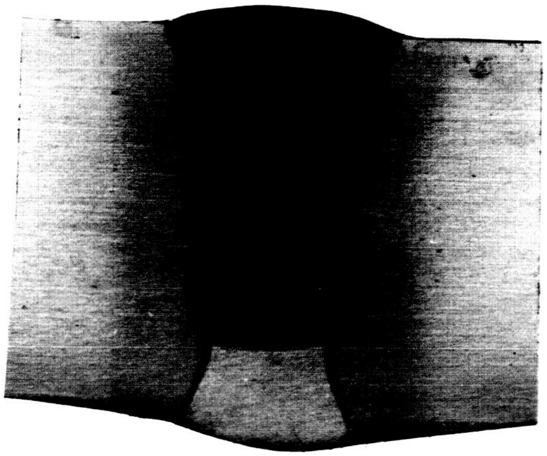


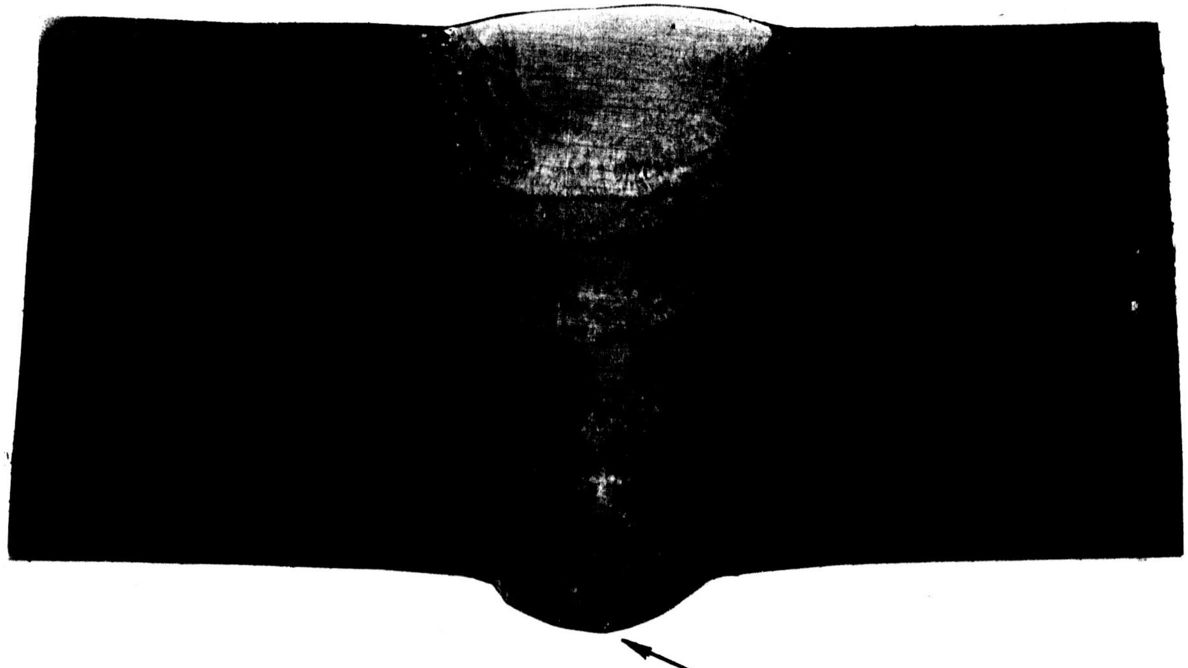
Figure 12
Weld Joint Made With Cross Seam Oscillator
5456 Aluminum - 3/4" Thk.
Automatic Vertical TIG Welding
Photomacrograph -3X



FORM 18-G-1 REV. 9-61

Figure 13

OVERHEAD WELD
3/4" 5456 ALUMINUM
MAG. - 4X



PHOTOMACROGRAPH OF ALUMINUM WELD
(OVERHEAD POSITION)

Figure 14

Root Pass
Without
Gas Backup

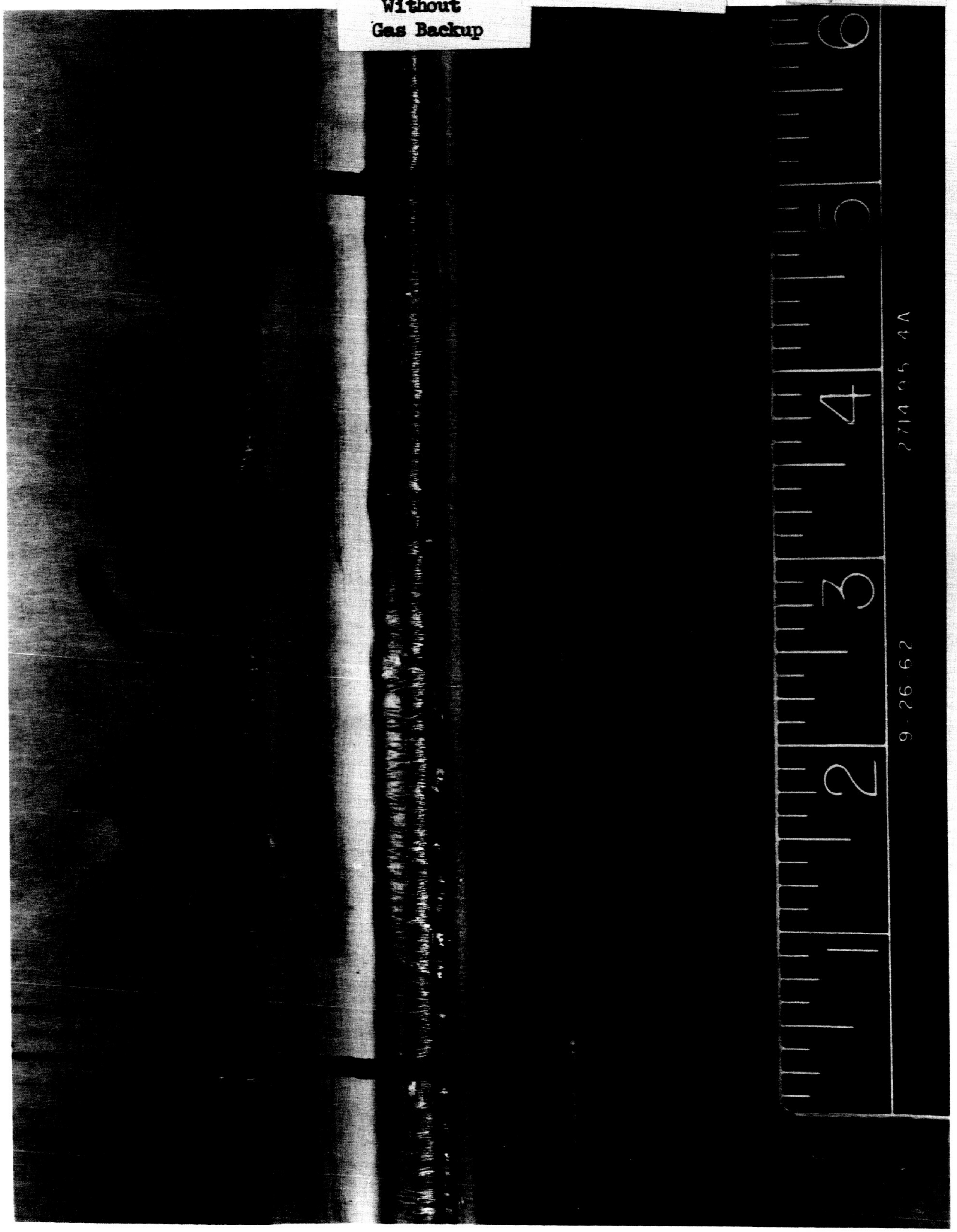


Figure 15

Root Pass
With
Gas Backup

6. CONCLUSION

6.1 Automatic out-of-position weave bead welding can be performed on 2014 and 5456 aluminum alloys in the overhead, vertical up and vertical down positions using cross seam, radius, and adjustable oscillators.

6.2 The radius and adjustable oscillators provide a greater guarantee of side wall fusion than the cross seam oscillator since the arc is rotated towards the side walls. The adjustable oscillator provides better torch control than the radius and cross seam oscillators since the weld bead width can be varied during welding.

6.3 Backing gas is recommended on the back side of the joint during root pass welding.

6.4 Improved sensitivity is required in the arc length control adjustment.

7. FUTURE WORK

7.1 The Phase III work which includes construction and delivery of equipment to NASA will commence immediately on receipt of NASA approval for this report and the Phase II results. Clarification of redirection of effort and equipment delivery as previously discussed with the NASA technical representative (Reference C and D) is also required.

8. REFERENCE

(a) Phase I Report, NA-62-864, "Determination of TIG Welding Control Parameters and Requirements For the Automation of Out-of-Position Welding"

(b) North American Aviation Fusion Welding Specification, LA-0107-004.

(c) Letter 62 LA-11386-283 From NAA, Inc., Los Angeles Division to NASA, Huntsville Alabama, dated 15 November 1962.

(d) Letter 62 LA-11455-280 From NAA, Inc., Los Angeles Division to NASA, Huntsville Alabama, dated 15 November 1962.